

DENITRIFICATION
POTENTIAL OF LOG JAMS IN
THE SANDUSKY RIVER, OHIO

by

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An Honors Thesis Submitted In Partial
Fulfillment Of The Requirements For

Graduation with Distinction

The Ohio State University

2005

Approved by _____

Dr. Tim Granata

Date _____

ABSTRACT

Denitrification Potential of Log Jams in the Sandusky River Ohio

Chairperson of the Supervisory Committee:

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Nitrogen in its oxidized form, Nitrate (NO_3^-), is considered a major pollutant of rivers and lakes in the United States, particularly in areas of high agricultural use. Nitrate is a nutrient that causes excess algal growth which can effectively suffocate aquatic life through a high biological oxygen demand by bacteria that decompose the algae. The effect of higher BODs can be to reduce oxygen to low levels resulting in uninhabitable conditions for some aquatic life. In addition to being detrimental to the health of water systems, NO_3^- in drinking water can have adverse health effects on infants, a condition called Blue Baby Syndrome.

The only way to prevent cycling of nitrate in aquatic systems is by denitrification, a biological process by which nitrate is converted to N_2 gas under anaerobic conditions and in the presence of organic material. Denitrification is a natural process in all river and wetland ecosystems. In this study, the potential for denitrification (DNP) in log jams of the Sandusky River was examined from a restoration design perspective. If log jams are a good source of denitrification substrate, it can then be inferred that the presence of exposed log jams have a positive impact on the health of the river system in terms of denitrification. This can provide an additional tool for understanding how dam removal, as a river restoration technique, affects the denitrification process. Dam removal may promote the creation and stability of log jams, thereby enhancing denitrification if

a relationship between log jams and increased denitrification potential is found. The primary hypothesis of this study is that log jams have an increased potential for denitrification with respect to its river, which is likely a result of reduced flow favoring build-up of sediments and organic material. Further, the potential for denitrification will increase in proportion to the size of the log jam.

The results of the study indicated that denitrification potential did not increase due to log jams with respect to the river. Furthermore, there was no significant relation between denitrification potential and size of the log jams. The results indicated that denitrification potential of the river, which consisted of samples collected from the river as well as the mudflat and floodplain, averaged slightly higher values. The floodplain values were highest and contributed most to the river average. Stream velocities and sediment types were analyzed in relation to denitrification potential as well. An expected trend of reduced stream velocities with increase in size of the jam was observed. It was expected that the reduced stream velocities, which indicates an increase in hydraulic retention time, would deposit finer sediments thereby creating a denitrification environment. However, the sediments collected from the log jams varied from sands and larger sediments to clays and silts and a consistency of denitrification between sediment types was not observed. Overall, the results suggest that denitrification is not enhanced by the presence of log jams due to increase in deposition of finer sediments because varied types and denitrification potential was observed for sediments associated with the log jams. Furthermore, this result was observed over varying size classes. The results suggest that log jams are passive in their influence on denitrification potential.

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ACKNOWLEDGMENTS

The author wishes to express a sincere thanks to the Faculty and Staff of The Ohio State University's Department of Civil and Environmental Engineering. Special thanks to Dr. Granata and Dr. Bouchard for their help with this project. I would also like to thank the ECOE lab group for there assistance as well. Thank you to my lab assistant.

INTRODUCTION

Nitrate (NO_3^-) is a water soluble form of nitrogen that is well known as a major pollutant of our Nation's rivers and lakes. This problem is especially evident in areas of high agricultural land use such as the Midwest where nitrogen is used as a fertilizer in the form of Ammonium (NH_4^+), which gets oxidized to nitrate. Nitrate is a nutrient that causes excess algal growth which can effectively suffocate aquatic life through a high biological oxygen demand by bacteria that decompose the algae. Low oxygen levels in river and lake ecosystems, known as hypoxia, can have a permanent effect on the system by forcing out endemic species and increasing the biological productivity of the system in a process known as eutrophication. A major example of this process involves the Mississippi River which collects river water from about one-third of the United States. Hypoxia in the Mississippi coastal waters affects the ecological balance and biodiversity of an area 18,000 km^2 in size (Hey, 2002).

Nitrate pollution can also have adverse health affects on infants who drink water with high ($> 10 \text{ mg/l}$) NO_3^- levels (Drinking Water: Nitrate and Methemoglobinemia, 2004). The result is methemoglobinemia or "blue baby syndrome" which is a blood disorder that affects infants and can be potentially fatal. River systems throughout the Midwest exceed this limit at various times (Hey, 2002) and excess levels have been recorded in the Sandusky River by current research at The Ohio State University.

The two processes by which nitrate can be reduced in river systems include reduced loading of NO_3^- through environmental management and denitrification, a method involving ecosystem removal of the nitrate. Denitrification is the biological processing of nitrate (NO_3^-) into nitrogen (N_2) and carbon dioxide

(CO₂) under anaerobic conditions. The anaerobic conditions necessary for denitrification typically occur within areas of high organic material and fine sediments (Allen, 1995), such as those found in log jams. In this study, the potential for denitrification (DNP) in log jams of the Sandusky River was examined from a restoration design perspective. If log jams are a good source of denitrification substrate, it can then be inferred that the presence of exposed log jams have a positive impact on the health of the river system in terms of denitrification. This can provide an additional tool for understanding how dam removal, as a river restoration technique, affects the denitrification process. Dam removal may promote the creation and stability of log jams, thereby enhancing denitrification if a relationship between log jams and increased denitrification potential is found. The primary hypothesis of this study is that log jams have an increased potential for denitrification with respect to its river, which is likely a result of reduced flow favoring build-up of sediments and organic material. Further, the potential for denitrification will increase in proportion to the size of the log jam.

This study will focus on a section of the Sandusky River in northern Ohio around river mile (RM) 50 where a low-head dam named St. John Dam was removed in November of 2003 (Figure A, Appendix). The St. John Dam and RM 50 are located in Seneca County. The Sandusky River watershed, which flows north and drains into Lake Erie, is characterized mainly by agricultural and rural land uses with increasing development and urbanization as the river travels toward its mouth at Lake Erie. There has been an increasing effort to remove low head dams across the country's waterways and restore rivers to a natural flow for environmental health reasons. However, few studies have been conducted on the affects of dam removal on denitrification (Granata, personal communication). This study will contribute to a previous study conducted on the same river system that examined the effects of the St. John Dam removal on denitrification in the

floodplain, mudflat, and river sediments (Nechvatal, 2004). Nechvatal's study concluded that dam removal, as a remediation for NO_3^- , had no significant effect as far as the river, mudflat, and floodplain sediments of the dam reservoir were concerned. In other words, the system had denitrification potential capacity to reduce nitrate loads in the sediment after dam removal even though wetted perimeter was lost. These findings are contrary to a model proposed by E.H. Stanley and M.W. Doyle that suggests denitrification, or nitrate retention, should essentially drop off after dam removal but return to pre-dam removal levels or above due to geomorphic processes following dam removal (Stanley and Doyle, 2002). Nechvatal's study suggests that the change in wetted perimeter associated with dam removal does not affect nitrate retention (denitrification).

In this study, the potential for denitrification as a tool for ecological restoration will be examined. If exposed log jams are determined to be a good source of denitrification substrate, it can be inferred that the presence of exposed log jams after low head dam removal, or in other naturally flowing river channels, have a positive impact on the health of the river system.

Hypotheses

Two hypotheses will be tested as follows:

1. Sediment from the log jams in the Sandusky River will have higher denitrification than the sediment in the river channel. It is theorized that this will be a result of greater availability of organic material and higher hydraulic retention time (HRT).
2. Denitrification will be proportional to size of log jams. It is theorized that the larger log jams will have higher denitrification ability due to increasing organic materials and HRT.

METHODS

The log jam sediment core samples were collected on March 22, 2005. The log jams were selected based on their size in two general areas within the previous reservoir of the St. John Dam. A total of nine log jams were selected for analysis which represented a range of size in the system from approximately 3 m² to 300 m² in plan view. Sites 1-3 were located near the intersection of County Road 6 and Township Road 131 in Seneca County, the prior dam location. The remaining 6 sites (sites 4-9) were located around the Hecks Bridge on Township Road 28. The Hecks Bridge is approximately 4.2 river miles upstream and is within the previous reservoir of the dam. Figure B in the Appendix is a photo log of the log jam sites and sediment samples. The sediment cores were obtained using a steel, 1-inch diameter corer. Most sediment samples were extracted from the top 6 inches of sediment while some sample cores were obstructed by bedrock, woody debris, or other obstacles and were limited to only a few inches of sediment. Three sediment samples were collected within and beside each site at different locations in the log jam and placed into re-sealable plastic bags where they were mixed to homogenize the sample. All samples were collected over an eight hour period and were stored at 4°C until analysis on April 7, 2005 (16 days later).

Each log jam size was estimated by measuring two horizontal axes with a tape measure. The area of each log jam, calculated by the two axes, was corrected by a subjectively derived factor in order to better represent the log jams actual sizes. This factor is merely a percent of the area created by the two axes derived from visual inspection. Classification of the log jams' size was established through analysis of the surface areas of the sample group of log jams.

The water velocity above each sample was measured using a Doppler Flow Tracker. The velocity of the water at each sample was used to calculate hydraulic retention time (HRT). Lower relative velocities will indicate greater HRT for fixed value.

Denitrification was measured in the laboratory by the acetylene block method using a Shimadzu GC-14A gas chromatograph (GC). This method uses acetylene (C_2H_2) to block biochemical reduction of nitrous oxide (N_2O) to nitrogen gas (N_2) in order to avoid the difficulty in measuring N_2 because of its ubiquity in the atmosphere (78.08%). The percent volume of N_2O in the atmosphere varies around 0.00003% (Pidwirny, 2005) and therefore does not have a significant potential for contaminating the sample and measurement. The rate of N_2O produced by each sample is accepted as the measure of denitrification rate assuming all the N_2O would be converted to N_2 . The half reactions of NO_3^- to N_2 (denitrification) are shown below along with the catalyzing enzymes (Rittman & McCarty, 2001, p. 498).

- $NO_3^- + 2e^- + 2H^+ \Rightarrow NO_2^- + H_2O$ Nitrate Reductase
- $NO_2^- + e^- + 2H^+ \Rightarrow NO + H_2O$ Nitrite Reductase
- $2NO + 2e^- + 2H^+ \Rightarrow N_2O + H_2O$ Nitric Oxide Reductase
- $N_2O + 2e^- + 2H^+ \Rightarrow N_2(g) + H_2O$ Nitrous Oxide Reductase

The acetylene inhibits the nitrous oxide reductase enzyme and can be seen from the process that 1 mole of nitrate yields 1 mole of nitrous oxide which in turn yields 1 mole of nitrogen gas.

For the lab analysis, approximately 25 mg of wet soil was placed into 120 ml bottles to which 25 ml of deionized water was added. Each bottle was then capped with a rubber septum and sealed with an aluminum collar. The samples were evacuated with a pump for approximately 10 minutes and then flushed with

helium in order to normalize the pressure in the bottles. Twelve milliliters of acetylene was added to each sample at time zero.

Gas samples were collected from the head space of each sample with a syringe through the septum at times 3, 6, 12, and 24 hours. Approximately half of the 125 ml bottles was head space. The syringe was pumped three times in order to mix the gas sample thoroughly. Approximately 6 ml of each sample was collected and injected into 5 ml bottles which had been capped, sealed, labeled and evacuated with the pump. All gas samples were stored in a refrigerator until analysis on April 23, 2005 (16 days later). Standard procedure for analyzing the gas samples with the GC was performed with assistance from Dr. Virginie Bouchard of the School of Natural Resources at The Ohio State University. The raw data produced by the GC are a concentration in parts per million (ppm) of N_2O , which was converted to mass in mg of N_2O assuming standard temperature and pressure of the 1 ml gas sample that was injected. The mass of the N_2O was divided by the dry weight of the soil for each sample. Dry weight was calculated by drying the remaining sediment from each sample at 110°F for 24 hours and weighing giving the units of mg N_2O /g Soil.

The acetylene block method of measuring denitrification is not an *in situ* measurement of denitrification because the samples are incubated and forced into a strictly anaerobic environment. For this reason, the measurement is considered a maximum value generated under ideal conditions or denitrification potential (DNP). The DNP rate of each sample was determined by linear regression of the mg N_2O /g Soil measurement over time which yields a rate of mg N_2O /g Soil/h. The rate of DNP for the 24 hour period fit a linear trend very well with R^2 values averaging 0.99 +/- 0.01.

RESULTS

The three samples per site were averaged and calculated for a standard deviation (SD). The DNP rates for every sample along with the means and SD are presented in Table C of the Appendix. In addition, Table C relays the water velocity (u) and soil type associated with each sample and the estimated size of each log jam. The table is provided for reference to actual figures used in the analysis.

Hypothesis: Log jams will have a higher DNP rate than the normal river channel.

Result: No significant difference between DNP rate and the river was found.

The first hypothesis being tested in this study is that the log jams will have a higher DNP than sediments in the river channel. It was hypothesized that the log jams will contribute to lower HRT and therefore a build up of sediments and organic materials which will in turn create and maintain the anaerobic layer in the sediment near the sediment-water interface necessary for denitrification to occur. The DNP rates of the river sediment in the Spring, Summer, and Fall of 2004 were compared by Nechvatal. For the purpose of comparing DNP rates at the same time of year, only the Spring river samples, which were collected by Nechvatal at the St. John Dam and Hecks Bridge area, will be compared. We will assume little to no difference in nitrate levels of the river system between these two sample times. In addition, we will assume the DNP rate is nitrate limited. This is substantiated by the Nechvatal study (2004) which determined that the system was nitrate limited versus carbon limited.

The log jams did not have a significant difference in DNP rate compared to the river, mudflat, and floodplain samples at the St. John Dam location ($p=0.58$) and the Hecks Bridge location ($p=0.51$). A two sample T-test with unequal variance was used to obtain the p values. Figure D (a) in the Appendix is a chart of DNP rate for log jams and the river samples for each location. The chart suggests that the river DNP rates may actually be higher for each location. However, the sediment samples collected by Nechvatal were from the river, mudflat, and floodplain of the two locations. When the four sediment locations are charted, as in Figure D (b), it is observed that the floodplain samples are much higher than the other three and are mainly responsible for the appearance that the river samples are generally higher than the log jams. Overall, there does not appear to be any significant relationship between the log jams and the other river sediments as the statistical analysis suggests.

Hypothesis: Logjam size should have a proportional affect on DNP rate.

Result: No significant relation between log jams size and DNP rate was observed.

To test whether log jam size had an affect on DNP rate, each log jam was classified into a size class as listed below. The number of jam sites in each class is listed as well.

Class	Range(m ²)	Sites
I	0-50	3
II	50-100	2
III	100-200	2
IV	200-300	2

Single-factor Analysis of variance (ANOVA) of the DNP rates per size class indicated no significant relation between size and rate ($p=0.04$, total $df=26$, $F=3.24$). when a significant criteria of 0.01 is used. This is clear when the mean DNP rate for each jam site is plotted against area as in Figure E in the Appendix.

The plot suggests that the log jam DNP rates tend to average around 0.06 mg N₂O/g soil/h (+/- 0.03) regardless of size. Additionally, all the mean values tend to have a relatively large standard deviation due to the rate variance of the three samples per jam. Log jam number 1 (S1) seems to be an outlier from the other jams.

When DNP rate is plotted against velocity of the water column associated with the sample in each size class, it is clear that increase in size of log jam is associated with lower velocities or greater HRT (Figure F, Appendix). However, there does not appear to be a difference between HRT and DNP rate. The Figure E plot does suggest that there may be a relation between stability of the DNP rate and size. That is, the largest size class (200 - 300 m²) rates tend to group more closely around an average rate value whereas classes I, II, & III have a wider range of values or deviation. This stability may be directly linked to the size suggesting that larger jams are more permanent and therefore have a greater ability to host and maintain the DNP conditions.

Figure G relates the relationship between stream velocity and log jam size. From this figure it can be observed that an increase in log jam size is generally associated with lower velocities. This relationship was expected as a result of the jam slowing down the water and increasing hydraulic retention time. However, this increase in stream velocity was not associated with reduced DNP rates as Figure H in the Appendix suggests. This plot of DNP rate versus velocity for all samples shows a few relatively high rates associated with low velocities however most tend to group around an average value regardless of size.

During the sample analysis it was noted that the soil types varied over a range of classifications but generally fell into two categories, clays and sands. Figure B of the Appendix contains a photo log of the log jam sites and wet soils for reference. Based on these two classifications, DNP rates were plotted against area

and velocity for the clay and sand samples in order to determine any significant relationships that might exist (Figures 1 & J). Although it is noted that the three highest DNP rates were associated with samples classified as sand and the three samples associated with the greatest stream velocity were classified as clay, there does not appear to be any significance of the rate as it relates to soil type ($p=0.15$, Two Sample T-test with unequal variance), log jam size, and stream velocity.

Overall, the results indicate that rate of denitrification and therefore the amount of nitrogen ultimately cycled out of the Sandusky River is not affected by the presence and size of log jams. The data suggests the log jams may play a passive role, when it comes to contributing to the creation of denitrification conditions. In other words, the DNP rates will be the same whether or not the log jam is present because the jams are not consistently creating the conditions necessary.

DISCUSSION

Areas of organic matter and fine sediments, such as those created by log jams are expected to be likely sites for higher denitrification levels (Allan, 1995). According to Allan, lower rates in sediments that are a mix of sand and gravel relative to fine grained sediments should be seen. This expectation is because the sands are more likely to have higher dissolved oxygen concentrations in the void spaces. The samples taken from the log jams contained both of these soil classes with no significant difference in DNP rate between them. However, it should be noted that the soil classifications were visually estimated in the lab and were not scientifically classified. Nonetheless, the jams hosted multiple types of sediment which were as varied as the DNP rates for the three samples taken per site. These three samples taken at random points in the log jams, due to this variability, did not consistently reflect a rate that could be associated with the particular jam. The basis for hypothesizing that log jams of the river would have higher DNP activity lies in the mechanics of the jams. They alter the flow in a way that promotes build up of these fine sediments and reduced dissolved oxygen levels. The results of this study suggest that effect was influenced by location within the jam. In summary, the sampled log jam sites exhibited sediment types and rates which were not consistent.

One of the challenges in understanding DNP associated with a log jam was in classifying the jam and determining what components characterize it (i.e. How much of the sediment surrounding the jam is considered part of the jam?). Log jams by nature vary greatly in composition, structure, and location in the river, not to mention life span. For this study, log jams were defined as non-moving woody debris in or at the side of the channel and samples were collected from the sediments that appeared to be influenced by the jam or present due to the jam. In

hindsight, because there is so much physical variation in log jams, it is only natural to expect values of DNP in and around the jam to vary relative to the river, especially within this definition of a log jam. The key to measuring a log jam for its DNP rate and nitrogen production would be to understand exactly how the areas with denitrification ability in a log jam are created and where they are located if they occur. To that end, a follow up study to this one may be entitled *Anatomy of a River Log Jam in Ohio* in which DNP is measured across a sample of log jams in a grid wise pattern and included a structural and morphological analysis. In this way DNP of log jams could be characterized by its true DNP value and compared to other jams with greater accuracy. Characteristics that could be classified for a log jam that might show a more consistent relation between the DNP rate and jam could include, but not be limited to, *location relative to channel (bank, middle, bend, etc.), submerged vs. non-submerged, age, and calculated volume of sediment build up and type caused by jam.*

A few possible explanations posited by the author regarding the inconsistent DNP rates are discussed as follows. As suggested previously, classification and better understanding of what “is and is not part of a log jam” would help in comparing the change in DNP created by the jam relative to its river if one existed. The hydraulic conditions created by our log jam sample group varied in their deposition of materials. Some of the jams with higher velocities (lower HRT) appeared to deposit sands rather than fine particles and organics while others did the opposite. This appears to have something to do with the physical structure and location of the jam. However, it can’t be asserted that all areas associated with each jam observed to have these characteristics was uniform in their sediment deposition. The fine silts and organic deposit caused by a jam considered to have deposited mainly sand and larger particles may have been overlooked during the survey. The samples collected may not have been from the sediment that was built up due to the jam and therefore probably represent the

rate of the river more than the jam which would explain the similar relation between the jams and the river sediments in some cases.

Another factor that may affect the results regarding a non-significant relationship between size and DNP of the log jam involves lack of detailed survey and classification of the sediments. It was suggested that larger log jams would have greater DNP due to increased deposition of fine sediments and organic materials which support build up of anaerobic conditions. Of primary interest is how much nitrogen is being removed from the system as indicated by DNP. When we consider DNP in terms of microbial activity, there are two ways that this build up of denitrifying environment can contribute to an increase in nitrogen removal. One is that the larger amounts of fine sediments and organics host a larger number of robust microbes due to a more stable anaerobic environment. This ultimately will lead to greater DNP rates and therefore cycling of nitrogen out of the river. The results indicate that this probably was not occurring and there was a relatively uniform rate over size. On the other hand, any increase in the amount of denitrifying environment created by the jam will produce more cycled nitrogen at any rate. In other words, we need to know how much denitrifying environment in terms of mass is present in the jam and multiply this by the DNP rate to measure the amount of denitrification occurring due to the jam. Hence, a more thorough survey of the types and amounts of soils and conditions present would be necessary to completely understand the DNP of log jams by size.

As a final note, an interesting feature of this study involves the DNP rate data which exhibited a surprisingly consistent linear function over the 24 hour period of analysis with average R^2 values of 0.98. Perhaps this finding would not be of interest to those seasoned veterans of the acetylene block method and gas chromatograph analysis. However, with all the steps involved, variables related to the samples and opportunities for error in measurement of such small amounts

of matter, it is surprising that the data was so consistent across almost all 108 gas samples. It seems difficult in concept to transfer a few ppm of anything between 3 vessels over a two week period.

Conclusions

The results of the study indicated that denitrification potential did not increase due to log jams with respect to the river. Furthermore, there was no significant relation between denitrification potential and size of the log jams. The results indicated that denitrification potential of the river, which consisted of samples collected from the river as well as the mudflat and floodplain, averaged slightly higher values. The floodplain values were highest and contributed most to the river average. Stream velocities and sediment types were analyzed in relation to denitrification potential as well. An expected trend of reduced stream velocities with increase in size of the jam was observed. It was expected that the reduced stream velocities, which indicates an increase in hydraulic retention time, would deposit finer sediments thereby creating a denitrification environment. However, the sediments collected from the log jams varied from sands and larger sediments to clays and silts and a consistency of denitrification between sediment types was not observed. Overall, the results suggest that denitrification is not enhanced by the presence of log jams due to increase in deposition of finer sediments because varied types and denitrification potential was observed for sediments associated with the log jams. Furthermore, this result was observed over varying size classes. The results suggest that log jams are passive in their influence on denitrification potential.

Recommendations for future studies on the subject include a detailed assessment of the log jam characteristics such as type and amount of sediments in addition to more systematic and extensive sampling of sediment from each log jam.

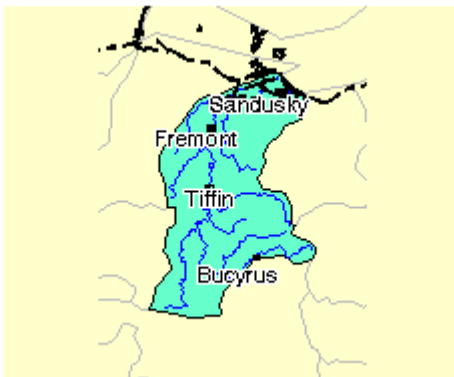
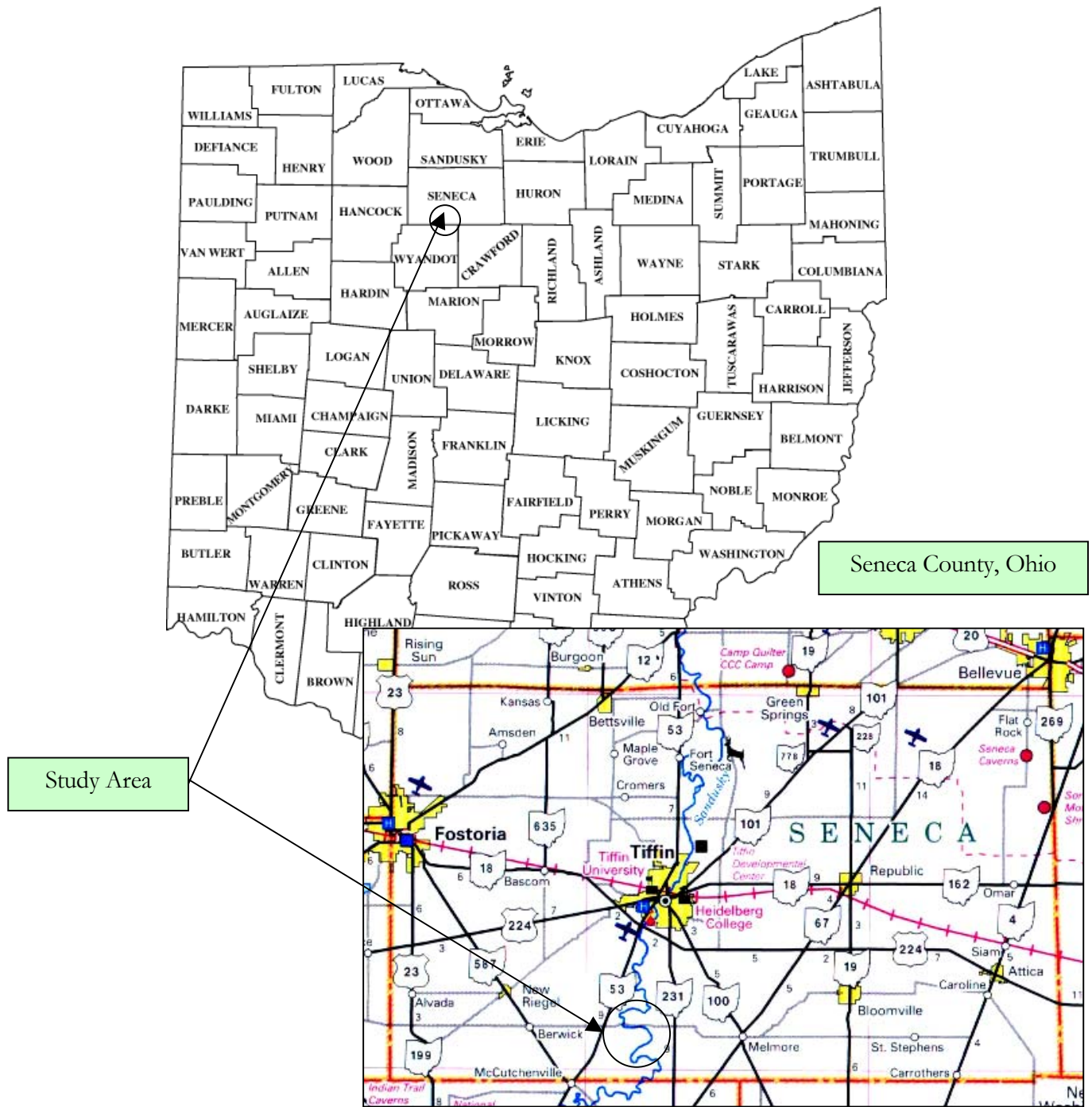
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EXHIBIT A

PROJECT LOCATION MAPPING

STUDY LOCATION



Ohio Mapping

Adapted from ODOT County Mapping

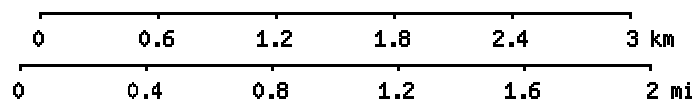
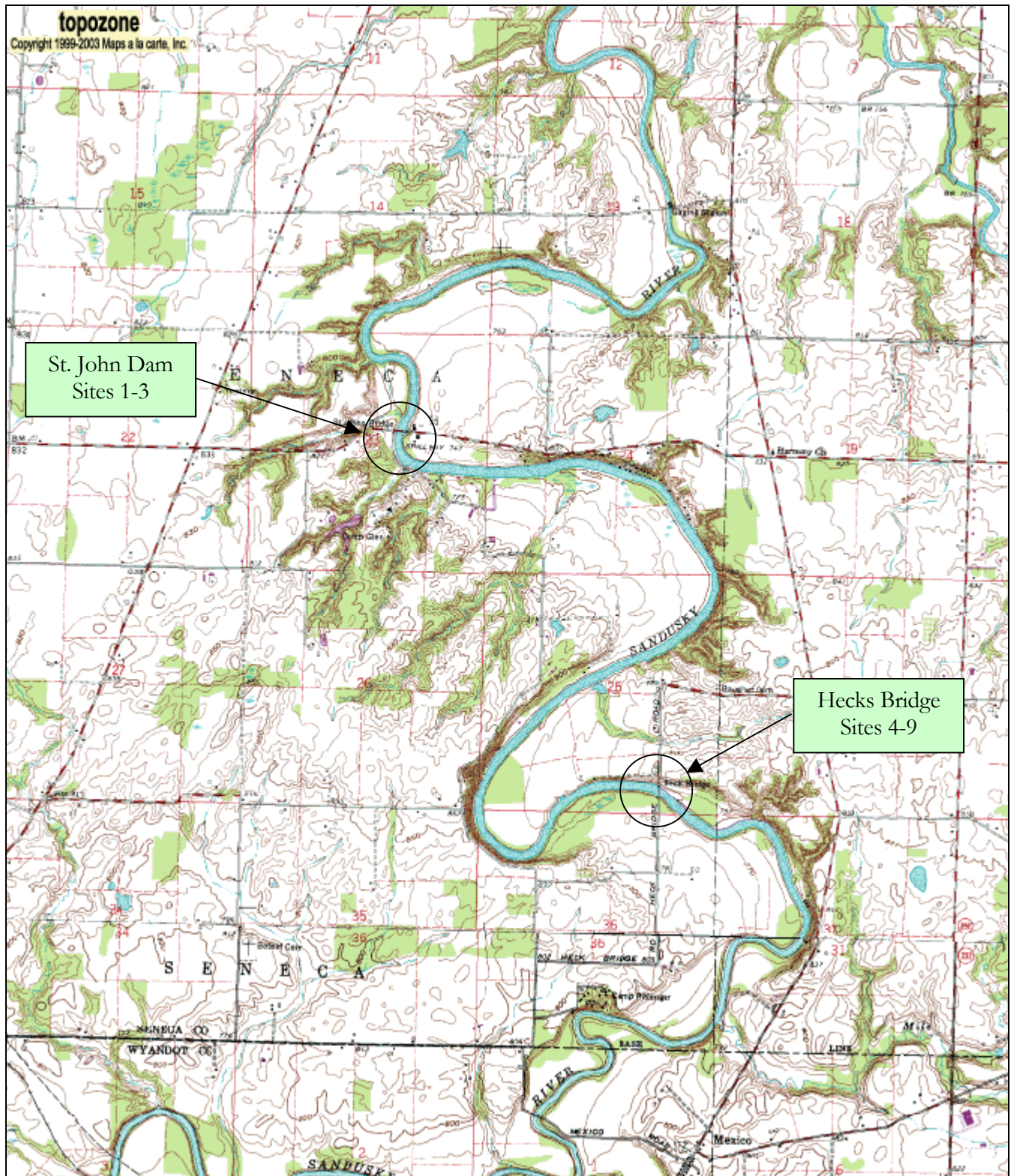
<http://www.dot.state.oh.us/map1/cntymap.HTM>

Sandusky Watershed

Map adapted from USEPA "Surf Your Watershed"

http://cfpub.epa.gov/surf/huc.cfm?huc_code=04100011

STUDY LOCATION



Map center is 41° 1.24'N, 83° 12.42'W (WGS84/NAD83)

Tiffin South quadrangle

Projection is UTM Zone 17 NAD83 Datum

Map adapted from TopoZone at TopoZone.com



M=-6.689
G=-1.449

EXHIBIT B

LOG JAM & SEDIMENT SAMPLE PHOTO LOG

SITE 1



Site 1
Log Jam



Site 1
Sediment Slurries



Site 1
Wet Sediment Samples

SITE 2



Site 2
Sediment Slurries



Site 2
Wet Sediment Samples

SITE 3



Site 3
Log Jam



Site 3
Sediment Slurries



Site 3
Wet Sediment Samples

SITE 4



SITE 5



Site 5
Sediment Slurries



Site 5
Wet Sediment Samples

SITE 5



SITE 7



Site 7
Log Jam



Site 7
Sediment Slurries



Site 7
Wet Sediment Samples

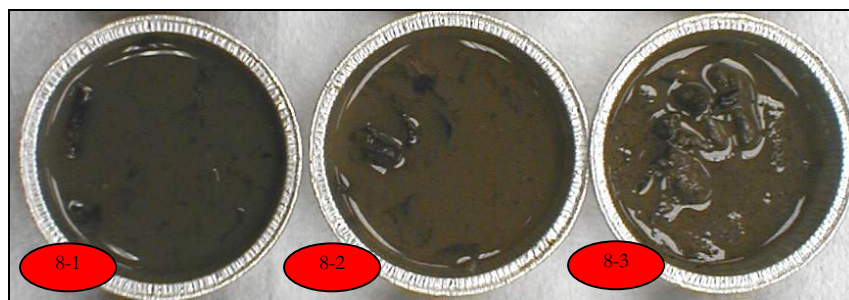
SITE 8



Site 8
Log Jam



Site 8
Sediment Slurries



Site 8
Wet Sediment Samples

SITE 9



Site 9
Log Jam



Site 9
Sediment Slurries



Site 9
Wet Sediment Samples

Site	Sample	Rate (mg N ₂ O / g soil / h)	R ²	Mean Rate	SD	u (ds)(cm/s)	Size (m ²)	Size Class	Soil Type
1	1.1	0.1618	0.9963	0.1123	0.046734	15.0	192	III	S
	1.2	0.1062	0.9982			15.0			S
	1.3	0.0690	0.9806			0.0			C
2	2.1	0.0531	0.9996	0.0475	0.007878	5.8	115	III	S
	2.2	0.0385	0.9924			11.1			S
	2.3	0.0509	0.9993			15.0			S
3	3.1	0.0553	0.9649	0.0365	0.017325	5.8	303	IV	C
	3.2	0.0211	0.9969			0.0			C
	3.3	0.0332	0.9717			1.4			C
4	4.1	0.0262	0.9860	0.0346	0.007231	7.9	3	I	S
	4.2	0.0393	0.9982			4.3			S
	4.3	0.0382	0.9906			42.2			S
5	5.1	0.0349	0.9986	0.0450	0.023412	82.2	5	I	C
	5.2	0.0282	0.9919			53.5			C
	5.3	0.0717	0.9906			75.4			C
6	6.1	0.1032	0.9854	0.0544	0.042296	0.6	39	I	S
	6.2	0.0288	0.9393			2.4			S
	6.3	0.0312	0.9964			12.0			S
7	7.1	0.0813	0.9889	0.0367	0.038666	0.1	52	II	C
	7.2	0.0174	0.9898			0.1			C
	7.3	0.0115	0.9902			0.2			C
8	8.1	0.0574	0.9888	0.0406	0.018575	1.7	274	IV	S
	8.2	0.0437	0.9982			1.7			S
	8.3	0.0207	0.9822			1.2			S
9	9.1	0.0112	0.9871	0.0202	0.014968	0.8	60	II	C
	9.2	0.0375	0.9709			18.7			S
	9.3	0.0120	0.9816			0.1			C

TABLE C – Data table representing DNP rate for each sample along with stream velocity (downstream), size class, and soil type associated with each sample.

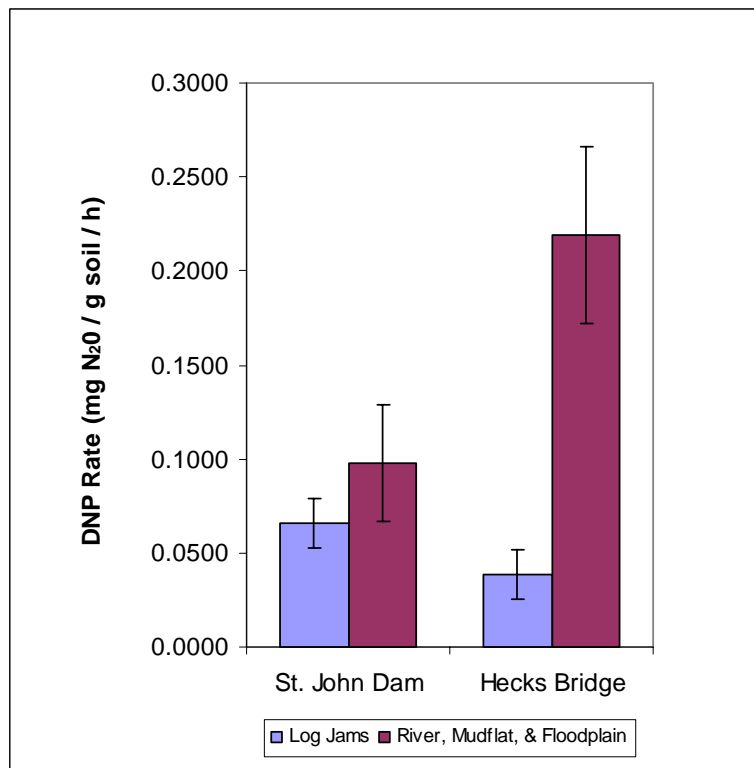


FIGURE D (a) – DNP rates of the river channel (average of river, floodplain, and mudflat samples) and log jams at the St. John Dam and Hecks Bridge area.

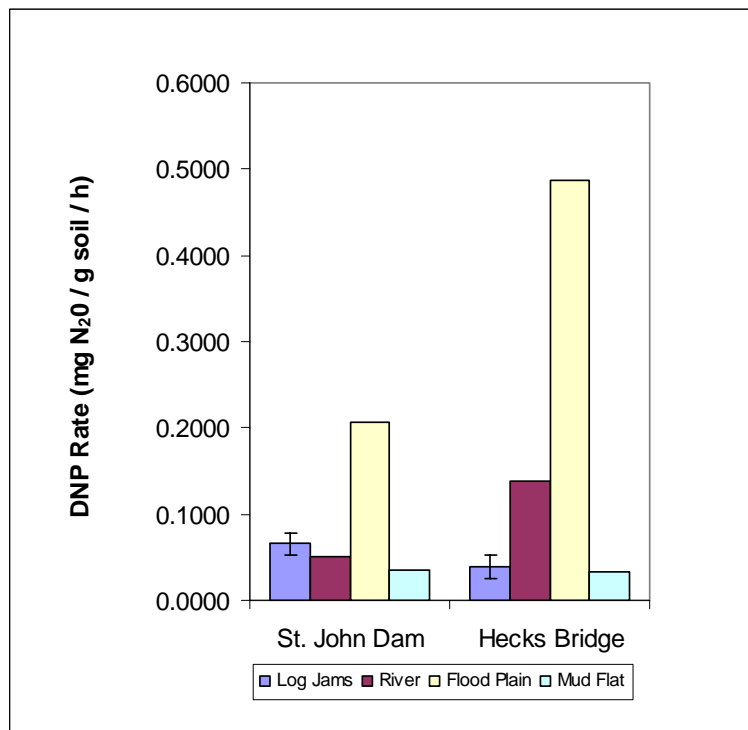


FIGURE D (b) – DNP rates of the log jams, river, floodplain, and mudflat samples at the St. John Dam and Hecks Bridge area.

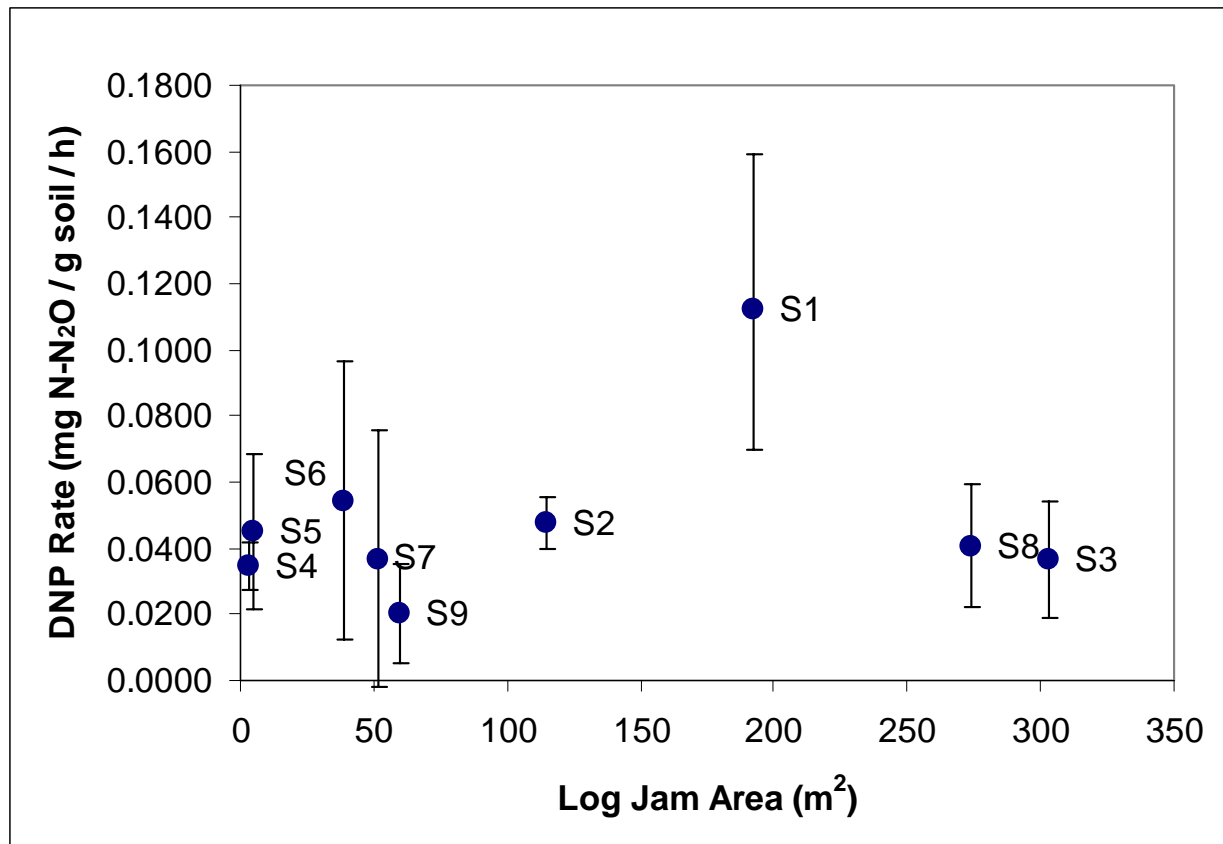


FIGURE E – Mean DNP rate of three samples per log jam as a function of log jam size in plan view.

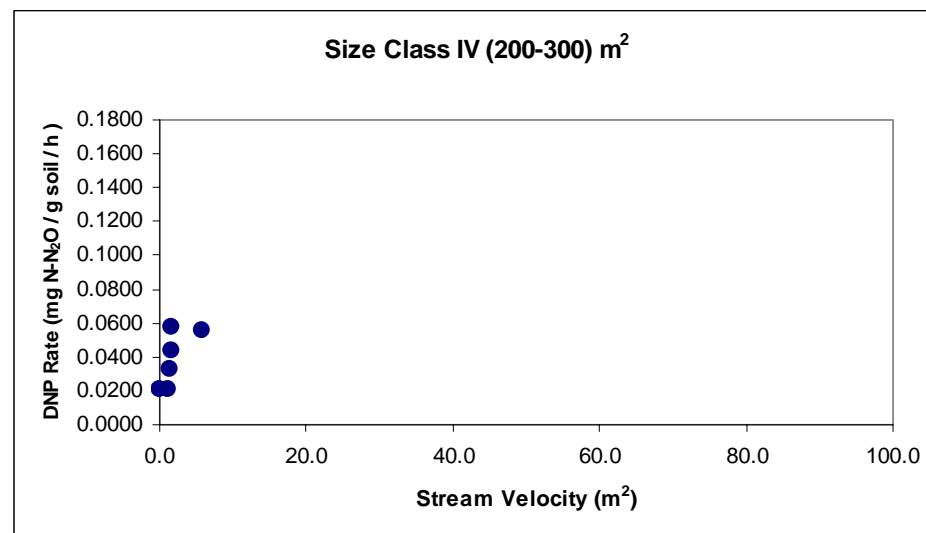
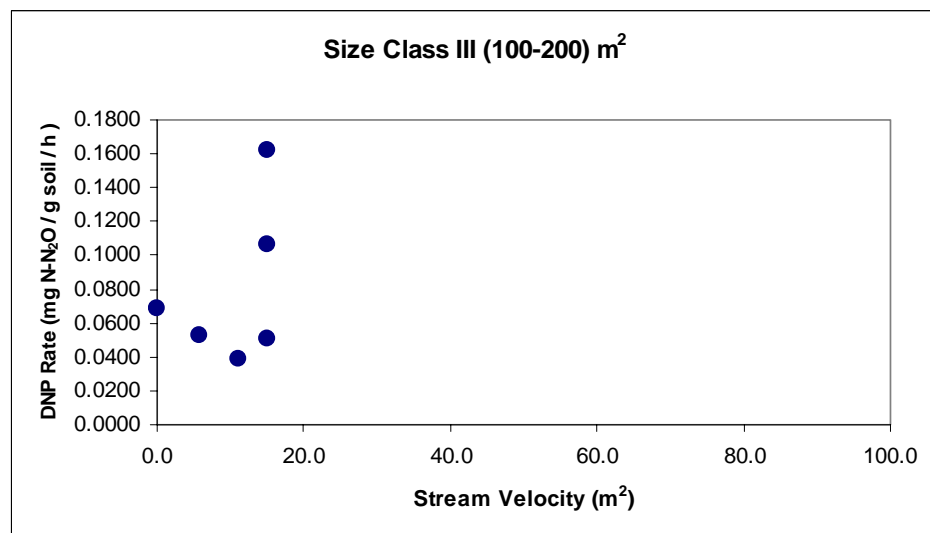
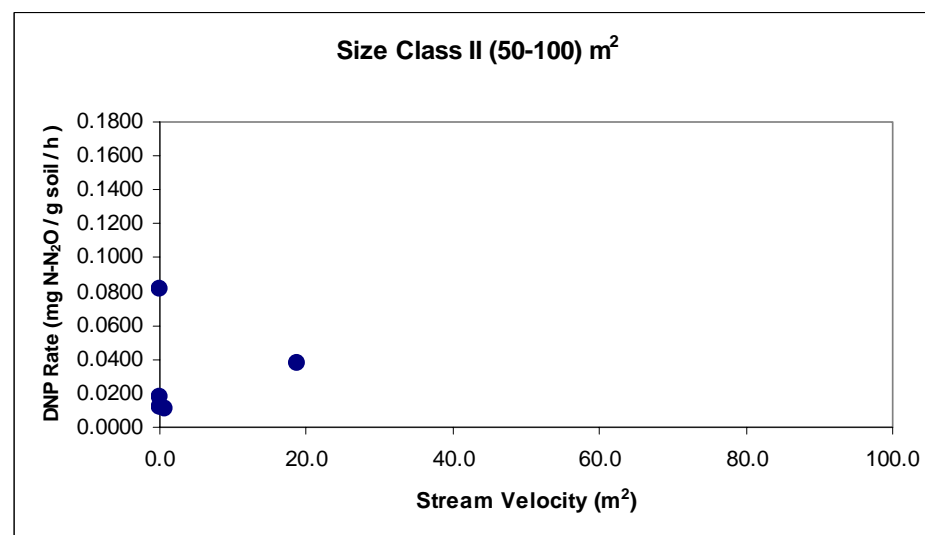
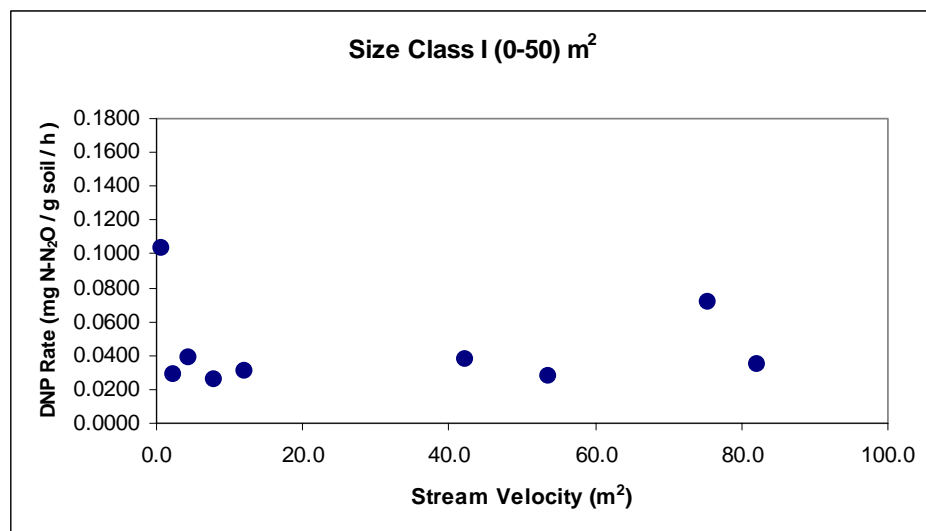


FIGURE F – Plots of DNP rate as a function of stream velocity for each size class.

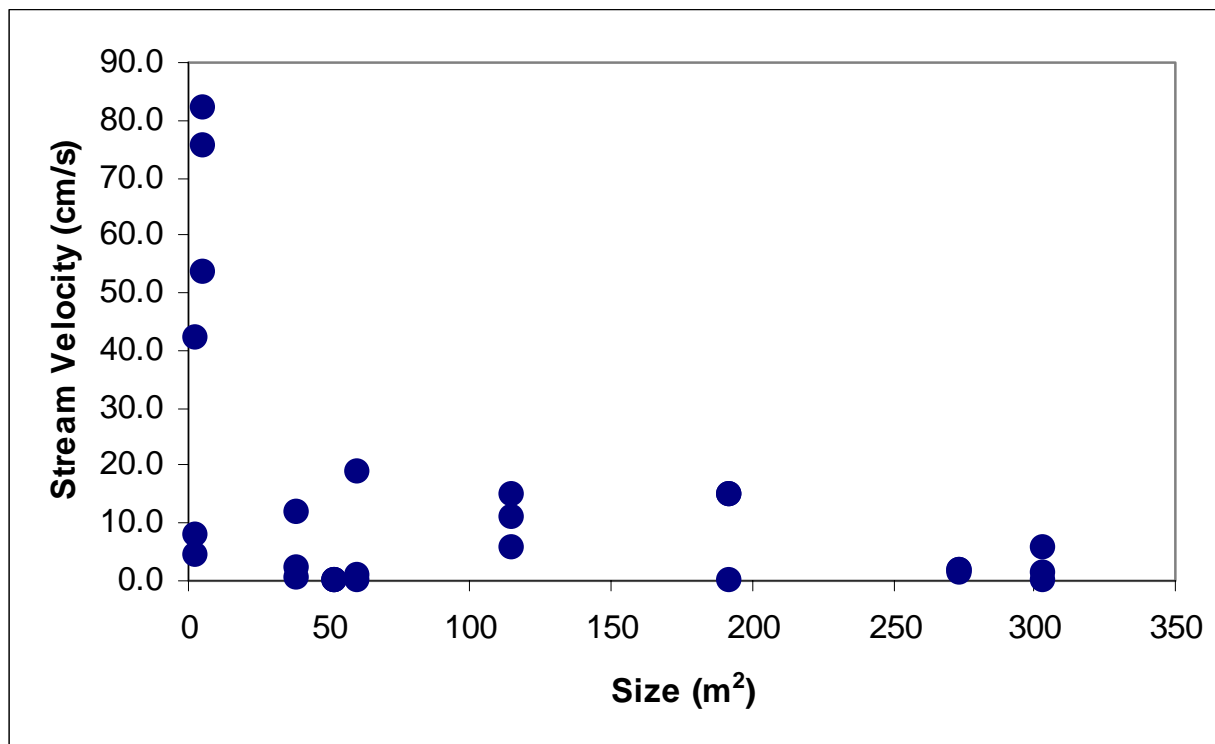


FIGURE G – Stream velocity associated with each sediment sample as a function of log jam size.

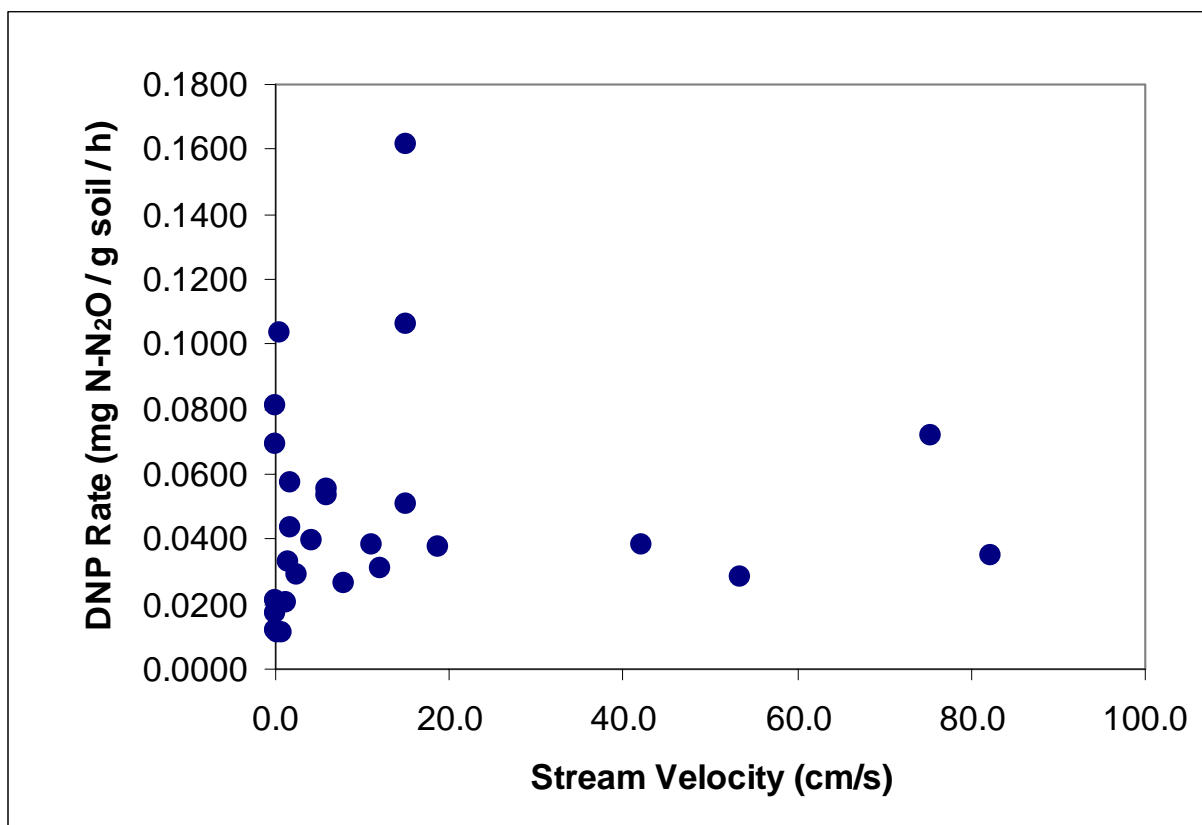


FIGURE H – DNP rate of each sediment sample as a function of stream velocity associated with the sample.

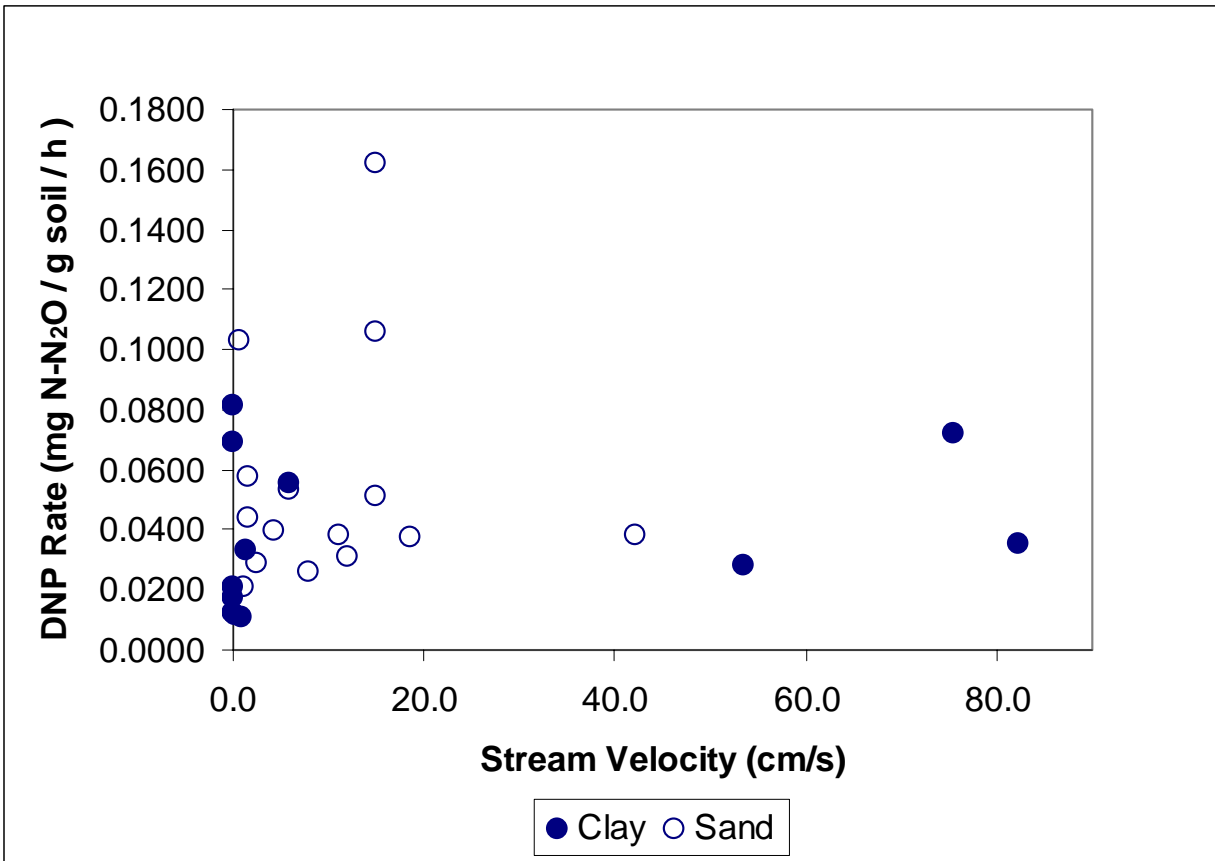


FIGURE I – DNP rate per sample as a function of river velocity at sample location for clay and soil.

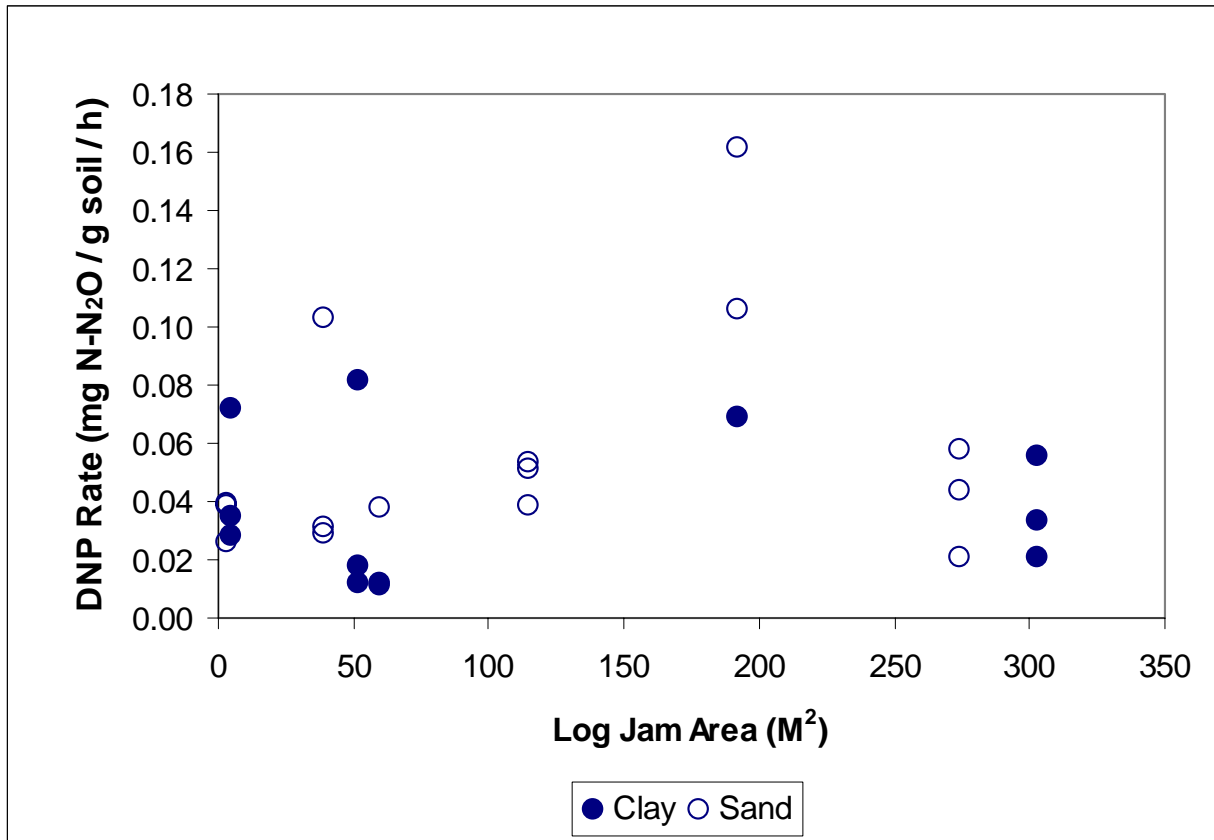


FIGURE J – DNP rate per sample as a function of log jam size for clay and soil.